Proposed NASA mission employs 'lobster-eye' optics to locate source of cosmic ripples

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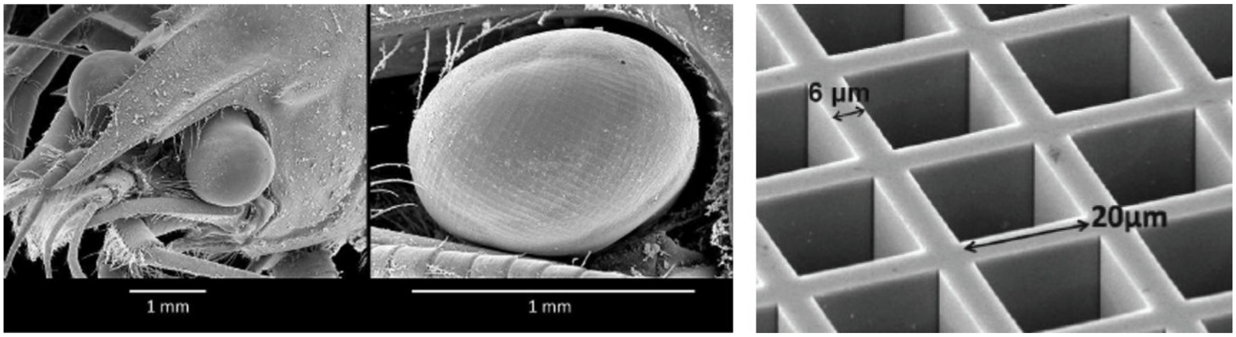

The Goddard-provided soft X-ray Wide-Field Imager proposed for a mission called ISS-TAO borrows heavily from nature. The images on the left and center show close-up views of a crustacean's eyes; the image on the right shows a manmade microchannel plate. Both operate the same way. Both gather light from multiple angles, focusing it into a single image to provide a wide field of view. Credit: J. Camp

A novel optics system that mimics the structure of a lobster's eyes would enable a conceptual Explorer-class mission to precisely locate, characterize, and alert other observatories to the source of gravitational waves, which are caused by some of the most powerful events in the universe.

The Goddard Space Flight Center in Greenbelt, Maryland, will study the feasibility of the Transient Astrophysics Observatory on the

International Space Station, or ISS-TAO. The mission was selected, along with two other similarly classed concepts, as a potential Explorer Mission of Opportunity. In 2019, NASA is expected to choose one concept for construction and launch.

"This mission is more relevant today than ever before," said mission Principal Investigator Jordan Camp, who is leading an international team to mature the concept and fine-tune its two instruments: a Goddard-provided soft X-ray Wide-Field Imager, or WFI, and the Israel Space Agency-provided Gamma-Ray Transient Monitor.

"The detection of gravitational waves in late 2015 was a watershed event," Camp said. "Gravitational waves are so different, so new. We want a way to connect conventional electromagnetic astronomy with this emerging science."

All-Sky Monitoring

From its perch aboard the International Space Station, or ISS, the mission would monitor the sky in search of transient X-rays and gamma rays—those fleeting, hard-to-capture, high-energy photons unleashed during black-hole and neutron-star mergers and supernovae. These powerful upheavals generate gravitational waves.

First postulated by Albert Einstein a century ago, gravitational waves are produced when massive objects moving close to the speed of light spiral together and merge in the universe. The movement and resulting collision create waves in the fabric of space-time, radiating out in all directions, much like how water ripples when a stone is thrown into a pond.

Last year in a bombshell announcement, scientists revealed that the ground-based Laser Interferometer Gravitational Wave Observatory, or

LIGO, had detected gravitational waves from not one, but two separate events involving the collision of black holes in other galaxies; others have been reported since. For this discovery, the three physicists who pioneered the LIGO facility—Rainer Weiss, Kip Thorne, and Barry Barish—recently were awarded the 2017 Nobel Prize in physics.

And then, on October 16, LIGO announced the first-ever detection of gravitational waves from the merger of two neutron stars. Less than two seconds later after the waves washed across Earth's space-time, NASA's Fermi Gamma-ray Space Telescope detected a weak burst of high-energy light—the first ever to be unambiguously connected to a gravitational-wave source. Half a day later, observatories around the world had found the location in visible light, pinpointing a gravitational wave source for the first time.

Currently, nearly everything scientists know about the cosmos comes from detecting and analyzing the light of cosmological sources in all its forms across the electromagnetic spectrum—radio, infrared, visible, ultraviolet, X-rays, and gamma rays. Each wavelength adds a different detail about the composition, temperature, and speed of these sources, among other physical characteristics.

The confirmation that gravitational waves do exist has opened a new window on the universe, giving scientists a new view that will complement what they already have learned through more traditional observational approaches. Camp, who helped develop LIGO's lasers and optics and was one of the authors on the paper announcing the first discovery, believes the mission has a special niche to fill in this emerging branch of astrophysics.

Special Niche in Gravitational Wave Science

The mission will be a sentinel, said mission Deputy Principal

Investigator Scott Barthelmy.

In addition to conducting all-sky surveys of transient X-ray sources, it will more precisely locate the X-ray counterparts to sources of gravitational-wave events, gather data, and communicate their position to other observatories so that they can begin their own observations.

"LIGO and Virgo (a recently upgraded interferometer facility in Pisa, Italy) form the advanced network of gravitational-wave observatories," Camp said. "They will alert us to the most exciting candidates, like the final moments of a compact binary system. Although these facilities can detect the ripples in space-time, they can't focus gravitational waves and instead achieve their source localization by timing of noisy signals," Camp explained. "Thus, they can't precisely locate their sources."

In contrast, the payload would point its lobster optics to the large portion of the sky identified by LIGO and Virgo and then focus the accompanying X-rays to localize and characterize these sources, he said.

Currently, the Hubble Space Telescope, the Fermi Gamma-ray Space Telescope, the Swift Gamma-Ray Burst Mission, the Spitzer Space Telescope, and the Chandra X-ray Observatory are looking for electromagnetic counterparts. Along with dozens of ground-based observatories, all of them detected light from the neutron star merger, allowing astronomers to study the aftermath of a gravitational-wave event for the first time.

However, the mission is particularly well suited for the task, said mission Co-Investigator Judy Racusin.

One of its instruments, the WFI, is equipped with the novel lobster-eye optics, which mimic the structure of the crustacean's eyes. Lobster eyes are made up of long, narrow cells that each reflect a tiny amount of light from a given direction. This allows the light from a wide viewing area to be focused into a single image.

WFI's optic works the same way. Its eyes are microchannel plates—thin, curved slabs of material dotted with tiny tubes across the surface. X-ray light can enter these tubes from multiple angles and is focused through grazing-incidence reflection, giving the technology a wide field of view necessary for finding and imaging transient events that cannot be predicted in advance. Other than in a sounding-rocket demonstration, lobster-eye optics have yet to be used in a space application, Camp said.

The mission's berth aboard the space station offers another advantage, said Mission Scientist Robert Petre, adding that the orbiting outpost provides communications, power, and other services that drive up the cost of spacecraft. "We want to use this amazing facility for exactly what it was designed to do—provide rapid, low-cost access to space."

Should ISS-TAO be selected as an Explorer Mission of Opportunity, Camp believes he could complete the mission and launch by 2022, just a few years after the scheduled launch of the James Webb Space Telescope. The Webb observatory also could be enlisted to observe the explosive events that generate gravitational waves, Camp said.

"We started work on this mission concept before LIGO made the discovery," Camp said, referring to R&D-funded efforts that began about five years ago. "The discovery of gravitational waves certainly has added a lot of excitement and opened a revolutionary new frontier in astrophysics. We think our mission can greatly enhance gravitational-wave science."

Provided by NASA's Goddard Space Flight Center

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